Application Report
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# Dynamic Power Path Management Simplifies Battery Charging from Solar Panels

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## ABSTRACT

The Texas Instruments bq2403x family of linear charge regulators were originally designed to charge single-cell Li-ion batteries from an AC adapter or USB port. However, these ICs also lend themselves well to applications powered by solar panels.

Solar cells basically comprise a p-n junction in which incident light energy (photons) causes electrons and holes to recombine, generating an electric current. As the p-n junction's characteristics are similar to those of a diode, the electrical circuit shown in Figure 1 is often used as a simplified model of the cell's characteristics.

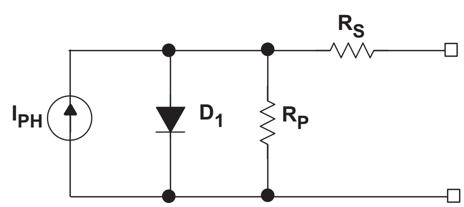


**Figure 1. Simplified Model of a Solar Cell**

The current source $I_{PH}$ generates a current proportional to the amount of light falling on the cell. With no load connected, nearly all the current generated flows through diode $D_1$, whose forward voltage determines the solar cell's open-circuit voltage ($V_{OC}$). This voltage varies somewhat with the exact properties of each type of solar cell, but for most silicon cells, it is in the range 0.5 V to 0.6 V (the normal forward voltage of a p-n junction diode). The parallel resistor $R_P$ represents a small leakage current that occurs in practical cells. As the load current increases, more of the current generated by $I_{PH}$ is diverted away from the diode and into the load. For most values of load current, this has only a small effect on the output voltage; there is a small change due to the diode's I-V characteristic, and a small voltage drop due to the series resistor $R_S$ (which represents connection losses) but the output voltage remains largely constant. However, at some point, the current flowing through $D_1$ becomes so small that the diode starts to become insufficiently biased, and the voltage across it decreases rapidly with increasing load current. Finally, when all the current generated flows through the load (and none through the diode), the output voltage is zero. This current is known as the solar cell's short-circuit current ($I_{SC}$) and, together with $V_{OC}$, is one of the primary parameters defining its operating performance (see Figure 2).

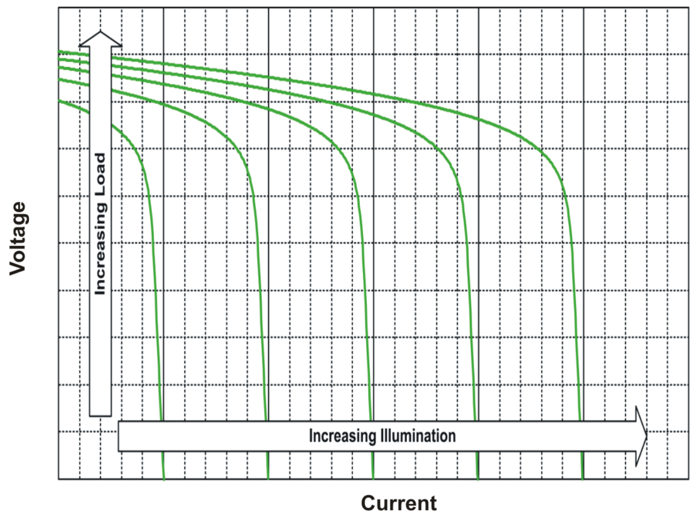


**Figure 2. Typical Solar Cell I-V Characteristic**

In most applications, it is desirable to get as much power as possible out of the solar cell. Because output power is the product of output voltage and current, it is therefore necessary to determine which part of the cell's operating characteristic yields the maximum value of VI. This is known as the maximum power point (MPP). At one extreme, the output voltage is at its maximum value ($V_{OC}$) but output current is zero. At the other extreme, the output current is at its maximum value ($I_{SC}$) but output voltage is zero. In both cases, the product of VI is zero; so, the MPP must lie somewhere between the two extremes. It can easily be proved (or experimentally observed) that in any application, the MPP actually occurs somewhere on the knee of the solar cell's output characteristic (see Figure 3). The problem in practice is that the exact location of a solar cell's MPP varies with incident light and ambient temperature. Systems designed to maximize solar power generation must therefore dynamically scale the current drawn from the solar cell so that it operates at or near the MPP under the actual operating conditions.

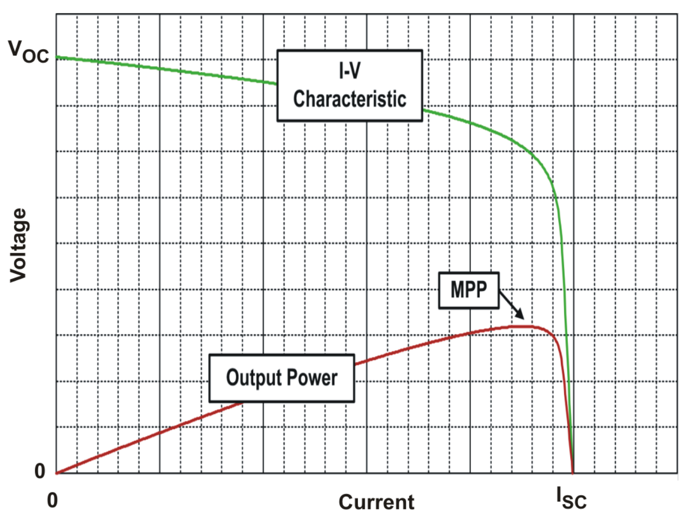


**Figure 3. Solar Cell Output Characteristics**

There are various ways to implement such a scheme – known as a MPP tracker – but these often become quite complex, especially in mission-critical systems such as satellites. However, in many smaller applications, an extremely accurate MPP-tracking scheme is not needed, and a simple, low-cost solution able to harness 90% to 95% of the available energy is all that is required. The dynamic power path management (DPPM) function of TI's bqTINY™-III family of linear charge controllers can be used to implement such a simplified MPP tracker.

The main elements of the DPPM function are shown in Figure 4. Ignoring the USB input for the time being, the circuit works as follows: $Q_1$ regulates the voltage at the OUT pin and $Q_2$ regulates charge current according to a typical CC-CV Li-ion charge profile. If the current available from the power source connected to the AC pin is insufficient to power the system and charge the battery, $V_{OUT}$ starts to fall. If $V_{OUT}$ reaches a predefined threshold, $V_{DPPM}$, the bqTINY-III automatically reduces the charge current to a level that maintains $V_{OUT}$ at $V_{DPPM}$.

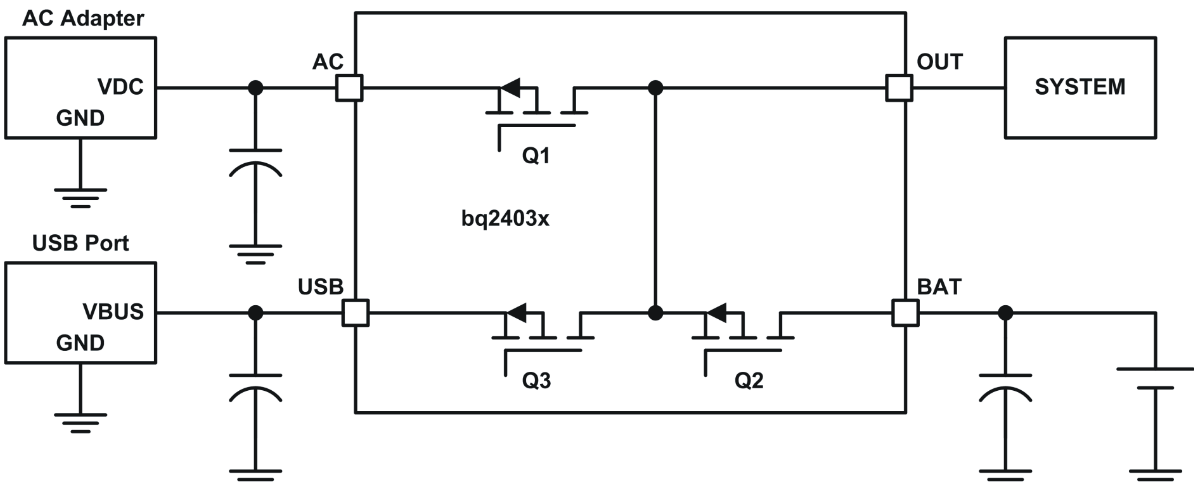


**Figure 4. DPPM Principle of the bqTINY-III Linear Charger**

This feature can be used in the application shown in Figure 5, in which a solar panel is used to recharge a single Li-ion cell. The solar panel comprises a number of strings, each with 11 silicon cells in series, and behaves like a current-limited voltage source, in which the current limit is determined by the size of the panel and the amount of light falling on it.

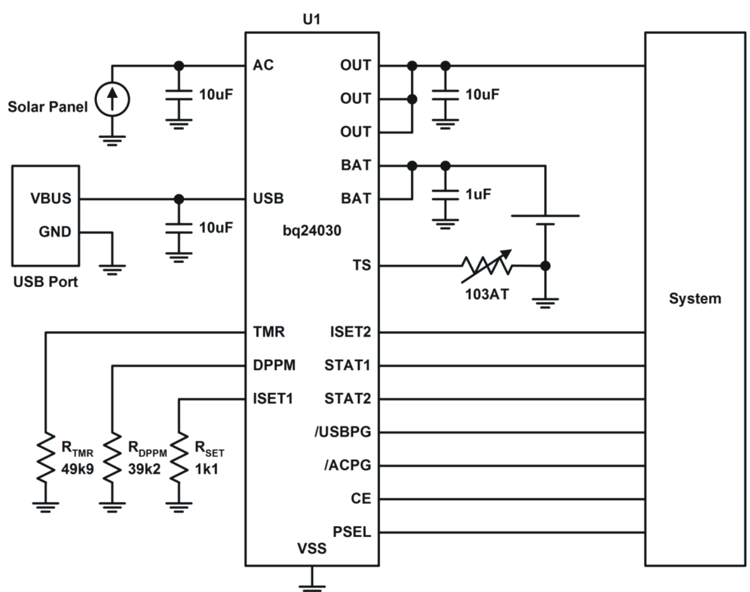


**Figure 5. Using a Solar Panel to Charge a Battery**

The maximum output voltage ($V_{OC}$) from this solar panel is typically between 5.5 V and 6 V. Because this is below the bq24030's predefined output regulation voltage of 6 V, $Q_1$ is turned on. $R_{SET}$ defines a maximum charge current of 1 A. If this exceeds its output capability, which depends on the available light, the solar panel's output voltage falls, reducing the voltage on the bq24030's OUT pin. $R_{DPPM}$ programs the bq24030 to automatically reduce $I_{CHG}$ to a level that allows $V_{OUT}$ to be maintained at a minimum of 4.5 V. This value of $V_{DPPM}$ was chosen because it corresponds reasonably well to the maximum power point

(MPP) of the solar panel. Assuming a voltage drop of 300 mV across $Q_1$ the voltage across each cell is equal to 436 mV, which maximizes the solar panel's power output. If $V_{OUT}$ is greater than 4.5 V, the DPPM function does nothing, and the solar panel moves away from its MPP, but this only happens if less power is needed than the solar panel can supply, in which case a reduction in efficiency is not important. It can be seen from Figure 3 that the output power curve is quite flat as it approaches the MPP and then falls off sharply. It is therefore better to set $V_{DPPM}$ slightly too high than slightly too low, so as to minimize the effect of an incorrect operating point on output power.

If the power available from the solar panel is insufficient to power the system even when the battery charge current has been reduced to zero, $Q_2$ turns on, $V_{OUT}$ drops to just below $V_{BAT}$, and the battery provides whatever current the solar panel is unable to provide.

The bqTINY™-III also allows the battery to be charged from a USB port. In this case, $Q_3$ is used to regulate input current to ensure that the USB specifications are complied with –100 mA or 500 mA, according to the state of the IC's ISET2 pin. If the sum of the system and charge currents exceeds the selected USB current limit, $V_{OUT}$ falls and the DPPM function reduces charge current or starts battery supplement mode as before.

Another useful feature of the bqTINY™-III family of devices is that the internal safety timer is automatically extended if DPPM is operating. Thus, under low-light or current-limited conditions, when battery charging is slower, the length of time allowed to recharge the battery before an error condition is indicated increases proportionally, preventing premature charge termination.